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# Tradition vs the new kid

Research on methods for measuring growth of *Acropora palmata*



Elias Speelman

WAGENINGEN MARINE RESEARCH  
CORAL RESTORATION FOUNDATION BONAIRE

Research report

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Wageningen Marine Research

Coral Restoration Foundation Bonaire

Elias Speelman

68569

Supervision:

Tim van Oijen (Hz University of Applied Sciences)

Erik Meesters (Wageningen Marine Research)

Francesca Virdis (Coral Restoration Foundation Bonaire)

Delta Academy

Water Management 4<sup>th</sup> year

Hz University of Applied Sciences

Vlissingen, The Netherlands

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## Abstract

The coral reefs around the world have been under very big pressure. In some places up to 95% coral coverage is already gone. For this big decrease there are many different causes, ranging from natural disasters to predation and sickness. Even humans have a big influence on the coral reefs. To protect the reefs around the island of Bonaire the Coral Restoration Foundation Bonaire has started to create replantation techniques. In this way the goal is to restore the reefs around Bonaire to how they were before the massive decrease. The main way of accomplishing this is by growing corals in nurseries.

This research focusses on the growing process in the nursery. In order to manage to the growth of corals in the nursery, a measuring method must be used. In this research 2 methods for measuring the growth of *Acropora palmata* (Elkhorn coral) were compared by means of a multi-criteria analysis. These methods were the linear extension and the 3d-reconstruction. The research question of this research was:

When comparing 3d-reconstruction to linear extension, which is the most reliable and practical to use in coral nurseries for measuring the growth of *Acropora palmata*?

To compare the 2 methods, the following criteria were used: time consumption, reliability, precision and type of results. The corals were measured with both methods.

For the time consumption, the linear extension was the best method. For the reliability, both methods were equal. For the precision, the linear extension was the best method. For the type of results, the 3d-reconstruction was the best method. All together with the weighting that was used in the MCA, the 3d-reconstruction method scored a little higher and was therefore in this research the best method.

However, both methods are useable for measuring coral growth and the use of either method should be evaluated for every research, as both methods have very clear strengths and weaknesses, that have been shown in this MCA.

## Acknowledgements

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I wish to thank Buddy Dive Resort for being able to use their facilities and providing us with dive tanks to complete this research.

Lastly, but most important to this research, I want to thank Owen de Vlieger for being my buddy, 'my assistant (most notably writing chapter 2.3, helping with rhino measurements and visualizing the graphs in chapter 4.1)' and mostly my friend during this research period. Without him I would not even have been able to start this research. I hope that one day we will be able to do a research like this again together!

I hope you will enjoy reading the rest of this report,

Elias Speelman

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## 1. Introduction

Coral reefs are one of the most productive marine ecosystems on the planet, but they are threatened. 19% of all coral reefs are already lost, and with current projections, another 35% will be lost in the next 40 years. Only 46% of the reefs are currently regarded as healthy and under no threat (Wilkinson, 2008). These projections do not include the effects of climate change, which can be devastating on coral habitats and are very unpredictable (Wilkinson, 2008). If the coral reefs all over the world are lost, this will have dramatic consequences for all (marine) organisms.

Coral reefs are not only a vital part of all marine ecosystems. The coral reefs around the world also provide food for a lot of people living close to the reefs and the tourism industry starts to depend on these ecosystems as well. Together this accounts for billions of dollars (Johnson et al., 2011).

Various causes can harm coral reefs, for example diseases, global warming and natural disasters. The most prevalent example of a disease is the white band disease. This disease is a bacterial syndrome that is known to cause high mortality in the *Acropora* genus (Aronson and Precht, 2001). Another frequently observed phenomenon is the so-called bleaching. This is when the polyps of the coral colonies expel the algae that live inside, the zooxanthellae. The polyps can survive for a while without the algae, because the polyps can catch food by themselves. This is not enough to completely cover their energy needs, which means that if the algae are gone for too long, the coral will die. Global warming increases the coral mortality, because at higher water temperatures bleaching is more prevalent (Brown, 1997). When the water temperature drops below a certain threshold, bleaching will also occur. Lastly, natural disasters can have a very big effect on the current coral reefs. Examples are hurricanes. Due to an enormous increase in wave energy, hurricanes destroy entire coral reefs. Branching corals, for example the *Acropora* species, are vulnerable to this increase in wave energy. These branching corals are however also able to recover relatively fast, due to their high growth rate (Wilkinson and Souter, 2008). However, the increase in wave energy can be beneficial as reproduction of these corals happens primarily through fragmentation.

For the Caribbean reefs, the species of *Acropora*, especially the *A. cervicornis* and the *A. palmata*, are very important. These species are relatively fast-growing and can, for this reason, also aid in the restoration of reefs (Johnson et al., 2011). Therefore, it is important to preserve these species of coral and to restore them in places where they have disappeared. To assess the success of a restoration effort, a method for measuring growth must be selected. A few methods have already been used, but the question is which one is the most effective and practical in the field. The method should not harm the coral and must be very accurate/precise.

This research contains a comparison between the traditional method, linear extension, and 3d-reconstruction, for measuring coral growth in the nursery. 3d-reconstruction has been used a lot for different purposes, but was recently discovered as a possible way of measuring growth of corals.

### 1.1 Research question:

The main research question of this project is:

When comparing 3d-reconstruction to linear extension, which is the most reliable and practical to use in coral nurseries for measuring the growth of *Acropora palmata*?

### 1.1.1 Sub-questions:

This research question will be divided into 3 different sub-questions:

1. Which method can measure growth in length, width, area and volume in a coral nursery setup?
2. Which method is the most precise in determining the growth of corals in a nursery set up?
3. Which method is the most reliable in determining the growth of corals in a nursery set up?

### 1.2 Hypothesis

The hypothesis for this research is that the 3d-reconstruction should be more useful and more precise than the linear extension. However, the linear extension is expected to be more reliable, as there are many ways through which the software used for 3d-reconstruction can fail. The usefulness of the 3d-reconstruction is primarily expected to be higher because it can measure not only length and width, which linear extension can measure too, but also provides area and volume. These last two measurements would prove to be more useful for measuring absolute growth of corals. The 3d-reconstruction is hypothesized to be more precise because it could measure in a lot more decimals than a measuring tape could. When comparing the methods with an MCA, the 3d-reconstruction is expected to get a higher overall score.

## 2. Theoretical background

### 2.1 Coral restoration

The importance of coral reefs should not be underestimated. The coral reef ecosystems all around the world are very important nursery grounds for fish and home to around one third of all marine life. This while only making up less than 0,1% of surface area of the earth (Reaka-Kudla, 1997). Even in an economical sense coral reefs are very important. They provide food for local people and provide the tourism industry with billions of dollars (Johnson et al., 2011).

As mentioned in the introduction, the coral reefs all around the world are under threat. If all coral reefs around the world would be lost, this would be an enormous disaster for among others the above-mentioned reasons. To prevent such a disaster a lot of restoration activities have been set up.

The *Acropora palmata* and *Acropora cervicornis*, are both considered as the most important corals for reef building purposes in the Caribbean Sea. Since the 1970s the population of these reef building corals drastically decreased, at some places with even 95% or more. There are many reasons for this rapid decrease, but the most important is believed to be white band disease (Precht et al., 2002).

Most of the coral restoration project include a nursery phase, which is used to reproduce corals via fragmentation and minimize stressors on the corals while they are still small. In this phase, measuring the coral growth is crucial.

### 2.2 Coral reproduction

There are two major ways in which coral can reproduce, sexually and asexually. The asexual part of reproduction can be divided into another two separate parts, being fragmentation and the growth of new polyps itself (Highsmith, 1982).

Fragmentation is defined as the separation of a live piece of a coral colony from the rest of the colony, due to breakage of the skeleton. This will result in two separate pieces of coral with exactly the same DNA to live on at a different spot (Highsmith, 1982). Fragmentation is by some believed to be the most common way to form new coral colonies in the *Acropora* species, although the research done on this subject is still debated (Boulon, 2005).

### 2.3 Coral nurseries

The rationale behind this practice is replacement of dead coral colonies with new ones to accelerate natural recovery. Several types of source material are available for transplantation. These include: transplantation of small or large, whole coral colonies, enhanced by deliberate seeding of planula larvae (Rinkevich B, 1995; Omori, 2003), transplantation of coral branches or fragments (Rinkevich, 2000; Soon and Chen, 2003), and the transplantation of nubbins (van Treeck, 1997).

The use of nurseries for coral restoration has become more common in the past decades.

According to Epstein et al. (2001), coral transplantation measures have frequently been employed as the prime management tool for restoration purposes.



Figure 2.1: nursery trees. Photo by Elias Speelman



“Gardening of corals”, the concept of mariculture of coral recruits in nurseries, in this case utilising the asexual reproduction of corals and growing them in the nurseries. These in situ nurseries contain structures coral fragments are attached to, to mariculture coral recruits in sheltered zones to an adequate size. Thereafter, the corals grown in the nursery are returned to degraded reef sites (Rinkevich, 1995). This strategy being used, is based on ideas of terrestrial forest plantation (Rinkevich, 2006; Rinkevich, 2005).

Floating coral nurseries provide improved environmental conditions for the corals. They have enhanced water flow, optimal light conditions, lack of sedimentation and elimination of corallivorous organisms (Shafir et al., 2006).

Particular Nursery: The Coral Tree Nursery ©

The Coral Tree Nursery © offers multiple advantages. The Tree incorporates better use of the vertical water column. This reduces drag and balances weight distribution more evenly, therefore making it much less susceptible to wave action damage. The capability of the Coral Tree Nursery to move in its entirety gives it the ability to move with tidal flow and wave energy, which keeps the structure longer intact. This is because of reduced stress on the framework.

Corals in The Coral Tree Nursery © show increased growth rates. Due to the vertical positioning of the trees, there is increased water flow and lack of substrate holdfast requirement. The vertical positioning offers multiple other advantages. Corals experience lower mortality from disease and benthic predators, like snails, fireworms and damselfish.

By limiting the surface area of the structure, maintenance is also limited. Less surface area gives algae less opportunity to grow (Nedimeyer et al., 2006).

## 2.4 Traditional

There are a few ways the growth of coral used to be measured. The use of the different methods depends on situation and available resources (Hill and Wilkinson 2004). The method which is mostly used in literature is linear extension (Davies, 1989; Gladfelter et al, 1978; Torres and Morelock 2002). This is the method that will be used during the research as a comparison for precision and ease of use.

## 2.5 The new kid

3d-reconstruction for coral is an extremely new field of research. Last year was the first time it was used to monitor the growth of *Acropora palmata* transplants in the field by the CRFB. This proved to be successful and is therefore suggested as a viable option for monitoring (Huisman, 2017). However, this research focused only on transplanted corals, no study has been done in the coral nurseries before. This research will therefore focus on using 3d-reconstruction in the nurseries. This might prove to be a bigger challenge, due to the hanging position of the corals, there is more possible movement involved and this might affect the models.

To use this method, 3 software programs are necessary. The first program is Agisoft, which will allow for a group of still photographs to be combined into a 3d-model. The second program is Rhino3d which is used to pull the measurements from the 3d-models in order to compare them to each other (Huisman, 2017). The last program (optional) is GOM player, which is used to create still images from a running video.

### 3. Method

A list of the materials used during this research can be found in appendix 1.

#### 3.1 Nursery work

The experiment was carried out in a temporary nursery, which is located at the dive site Oil Slick Leap on the island of Bonaire (Coordinates: 12.200191, -68.308590) (figure 3.1). The corals that were growing in this nursery are from 14 different genotypes and came from other, already established nurseries around Bonaire. In these nurseries, a total of 25 different genotypes of *Acropora palmata* were present, which were harvested from natural populations around the island of Bonaire. For this research only 4 of those genotypes were used. The genotypes have been selected based on the size of the corals (the ones large enough to be cut). There have been no studies so far on these genotypes to indicate an existing difference in growth rate and/or resilience against diseases and predators.

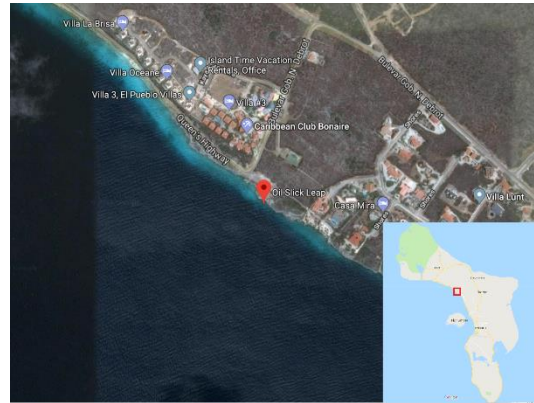


Figure 3.1: location of the temporary nursery located at the dive site Oil Slick Leap (source: google maps)

At the beginning of the research, fragments of *Acropora palmata* were cut. This means that from the corals growing in the nursery, a small part has been cut and this grew into a new separate coral with the same DNA. For each of the four genotypes, six new corals were created. This means a total of 24 new corals have been placed in the nursery to grow. These are the only corals that have been used during this research. Every coral had its own tag to prevent any mix ups and allow for tracking over time.

To place the corals in the nursery trees (as seen in figure 3.2), the coral had to be tied. A monofilament line held by a metal crimp sleeve was looped around the coral. This was then pulled as tight as possible to prevent any movement between the coral and the line. If the coral moved, it would not be able to grow over the line and crimp. The other end of the string is put in the nursery tree, secured with another metal crimp. All corals are hung at approximately the same depth to rule out depth as an influence on the growth.



Figure 3.2: Diver hanging *Acropora palmata* in a nursery. Photo by Owen de Vlieger

Before the pieces of coral were tied up in the nursery trees, the first set of data was collected for both the traditional method and the 3d-reconstruction.

#### 3.2 Set up

The experiment was carried out on a boat, because the corals underwater, either suspended or laying at the bottom, were moving too much relative to their background to create an accurate 3d-model. To overcome this difficulty, the corals had to be taken out of the water for a short period of time. The corals were brought to the surface in separate groups at different time, sorted by genotype, this meant six corals at a time. When at the surface, the corals were transferred to a box with seawater. The corals were in there for around 30 minutes. Previous researched conducted by CRFB has shown that for *Acropora cervicornis* this has no negative effect (Owsianka, 2018) and the

assumption was made that this would not be harmful to the *Acropora palmata*. This assumption was made because these two coral species are relatively close related. During the research, no negative effects were observed. The corals were then, one by one, put on a small block of wood with two markers and the coral tag, as seen in figure 3.3. The markers were placed for a better alignment in Agisoft and to have a known measurement in Rhino. The 3d-reconstruction method and linear extension methods were then applied (explanation of these methods follows in the next part). Each individual coral was out of the water for a maximum time of five minutes. After this procedure the corals were put back in the coral nursery.



Figure 3.3: experiment set up. Photo by Elias Speelman

### 3.3 3d-reconstruction

For every coral, two short movies were created with a GoPro hero 4. The second movie was a backup in case the first movie failed. This was done by going around the coral, which was on top of the wooden block, with a camera. Ideally nothing was moving in the background, as this would create problems in the steps later on. This movie was generally around 1 minute 20 to 1 minute 40. Every part of the coral had to be visible in the movie. From this movie around hundred frames were pulled with the program GOM player. These pictures were loaded into the program Agisoft. For this program to function properly, the pictures needed to have around 70% overlap.

When the pictures were loaded in Agisoft, the first step was to align the pictures. This was generally done on medium settings, with generic preselection and the tie points set to zero. If the alignment failed, for example less than 90% of the pictures were aligned or the alignment did not match the coral, the alignment would be rerun. This rerun was done with combinations of different settings (high accuracy, no generic preselection, 4000 tie points), until the alignment was good. The second step was to create a dense point cloud. This was generally run on medium quality with mild depth filtering. If the result was not sufficient, it was rerun on high or ultra-high settings. If this was still not sufficient, the alignment would be rerun. The third step was to create the mesh of the model. This was done on high settings with interpolation enabled. The last step was to create the texture, for this the default settings were used with hole filling enabled. If the model was not sufficient after this step, the alignment or dense cloud would be rerun. If the model was sufficient, it was exported as an .obj file for use in Rhino.

### 3.4 Rhino measurements

To work with the model in Rhino, the obj file created in Agisoft had to be imported. The file was imported in a template; Small Object – Centimeters. When the model is imported, it is shown in four different perspectives: Top, Perspective, Front and Right. In order to analyze the model properly, the view of all four viewports must be changed to 'Rendered'. After this step, the model had to be orientated in the right way. This was done with the command 'rotate'. The next step was to scale the model. The markers in the model served as the known dimensions. Using the 'scale' command, the model was scaled. After this an interpolated curve was put around the base of the coral, where it was attached to the wooden block in the model. With the command 'splitmeshwithcurve' the coral was split from the rest of the model. The next step was to use the command 'fillmeshholes' to create a solid object of which the volume could be measured. After this the area and the volume were measured with the commands 'area' and 'volume'.

### 3.5 Linear extension

With a measuring tape the length and width of the coral was measured. A photo was made to later determine the exact measurements.

### 3.6 Workflow

Over time, the experiment was repeated three times. The first time was when the corals were cut. Directly after cutting the corals, they were brought to the surface and measured on the boat. This happened on the 14<sup>th</sup> and 15<sup>th</sup> of March. The second measurement was taken exactly 3 weeks later, on the 4<sup>th</sup> and 5<sup>th</sup> of April. The last measurements were taken 20 days after the second batch. This was on the 24<sup>th</sup> and 25<sup>th</sup> of April.

### 3.7 Multi-criteria analysis

A multi-criteria analysis is a tool to structure a decision based on different criteria. This is widely used in research many research fields. The first step in the multi-criteria analysis is to form the criteria on which the methods (in this case) are tested. The second step is to create a score for each criterium and give it a weight. The third step is to test the methods based on these criteria and give them a score accordingly. The final result will be a score for every method tested and the method with the highest score is the one that preformed the best in the MCA (Dogson et al., 2009).

#### 3.7.1 Criteria

The different criteria that have been used in the multi-criteria analysis were the time consumption, the reliability, the precision and the type of results that the method will give.

CRITERIA	3D-RECONSTRUCTION	LINEAR EXTENSION
TIME CONSUMPTION		
RELIABILITY		
PRECISION		
TYPE OF RESULTS		

Table 3.1: Criteria of the MCA

The time consumption is the time that it takes from doing the experiment to extrapolating the measurement. This time was measured per batch of corals, which were in this case 24 corals. The time will be calculated per coral. This will be measured in hours. One day of work is 8 hours and 1 week of work is 5 days, this means 5 times 8 hours, which is 40 hours of work. This time is an estimation, as it was not tracked up to the minute. In this research, the data analysis had to be finished within 2 weeks or 80 hours. Therefore, the minimum score of 0 for this criterium is at 80 hours or more per batch, which translates to 3,33 hours/coral. The maximum score of 1 is in 0 hours. A linear relationship was used.

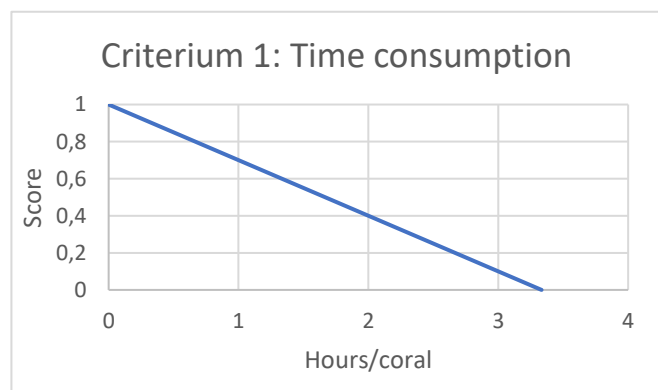


Figure 3.4: Score for the MCA for the criterium time consumption

The reliability is the percentage of measurements that were successful. This will be expressed in percentage of the measurement that was successful. For the 3d-reconstruction only the second and third batch will be used in this criterium, as the first batch had a lot of models that failed due to inexperience of the one holding the camera. These fails had nothing to do with problems with the actual method and therefore will be excluded for this criterium.

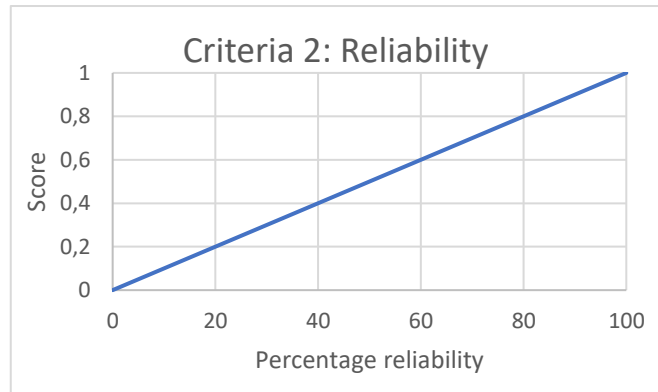


Figure 3.5: Score for the MCA for the criterium Reliability

The third criterium was the precision of the measurement. For this criterium the best scoring method was the one that showed the best relationship between all the measurements. The big difference with the accuracy and the precision is that to measure accuracy, the measurements have to be compared to an absolute measurement. For this research there was no absolute measurement and therefore the accuracy could not be measured. Instead for this research, the precision was used, which is whether the results from the measurements are similar. This is also explained in figure 3.6. After all data was collected, the length measurement of the traditional method and the 3d-reconstruction method was plotted into one graph. A trendline was created for both methods. From this trendline the  $R^2$  and the slope were taken. A two-tailed paired t-test was run on the different slopes. If this test gave a p of above 0,05, the measurement was presumed to be similar and therefore the  $R^2$  could be compared. The comparison between the  $R^2$  was done by taking the average. The  $R^2$  ranged from 0 to 1 with 1 being to most on one line. For this research a  $R^2$  of 1 was optimal and would score 1 point and a  $R^2$  of 0 would be the worst score and would get 0 points. A linear relationship was used. This meant that the  $R^2$  and the score would be exactly the same.

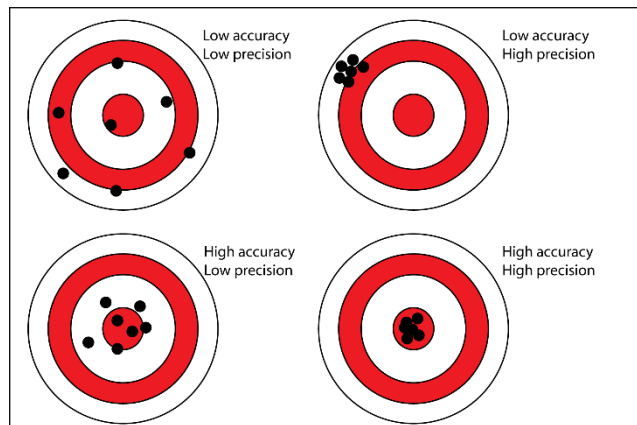


Figure 3.6: Difference between precision and accuracy

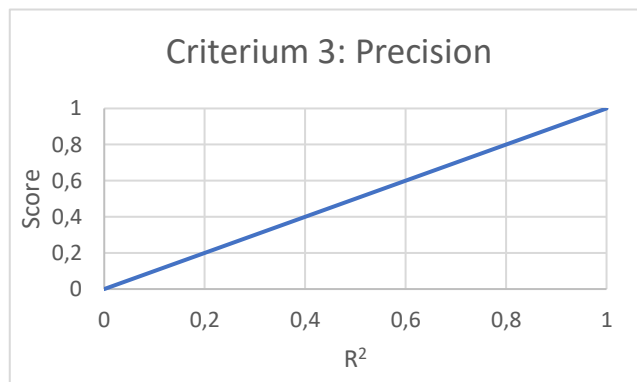


Figure 3.7: Score for the MCA for the criterium Precision

The last criterium was the type of results that a method could provide. This criterium was measured differently from the others, as there was no possibility to create a scaling for the scoring. The method either was or was not able to provide a certain type of results. The 4 types of results that were possible outcomes during this research were volume, area, length and width. As length and width were very closely related and every method that could determine the length could also determine the width, these were seen as one

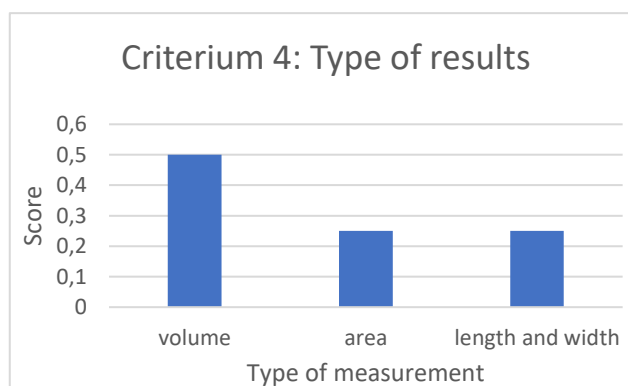


Figure 3.8: Score for the MCA for the criterium Type of results

type of result. The length and width were the least important type of measurement that a method could provide, because *Acropora palmata* doesn't grow at equal speed in every direction. This means that the maximum length can be in a different angle or position after a period of time. This would not give an accurate representation of the growth of the entire coral and won't allow for comparison over time. If the method was able to measure the length and width, it would get 0,25 points. The next possible measurement is the area. During this research there were some problems with the measurement of the area of the coral, which made these highly unreliable, therefore during this research these measurements were left out. In the discussion the problem with the area measurements is explained more detailed. The area of the coral is a more fair representation of the growth of the entire coral. The problems originate from the fact that the corals are not attached to a substrate, which is never the case in a nursery tree setup, which this research focuses on. For this reason, the score for a method that was able to measure area would only be 0,25 points. The last type of result that a method could provide is the volume. This was the most efficient way of measuring the growth of a coral, as this incorporated growth in every single direction at the same time. This is the most useful way for research to estimate the growth of a single or even multiple coral. If a method was able to measure the volume, it would get 0,5 points. If a method was able to measure multiple types of results at the same time, the points for these types of results would be added together.

### 3.7.2 Weight

The criteria that were deemed important received a weight of 1. These are also the criteria that are directly related to the sub-questions used during this research to determine the practicality and reliability of the method. The criteria that were deemed less important and that were not directly connected to the research or sub-questions received a weight of 0,5. For the final score for the MCA the score of the criteria is multiplied by the weight of the criteria. This can be seen in table 3.2

CRITERIA	CRITERIA WEIGHT	MAX SCORE	FINAL MCA SCORE
TIME CONSUMPTION	0,5	1	0,5
RELIABILITY	1	1	1
PRECISION	1	1	1
TYPE OF RESULTS	1	1	1
MAXIMUM MCA SCORE			3,5

Table 3.2: Full overview of MCA scoring including weight



## 4. Results

First the general growth results from this research are presented per coral. After this the results regarding the MCA are presented and finally the score of the MCA is put together.

### 4.1 General Results

The next figures show the increase in length(growth) of the corals over time for both methods. The blue line represents the growth of the coral measured with the traditional method and the orange line is the same growth measured with the 3d-reconstruction method. The corals are grouped per genotype. The genotype is the number after the AP..., the individual coral number is after the Co.... The growth of the individual corals ranged from 0,2 to 1,5 cm. In appendix 2 a full table with all results from both method can be found.

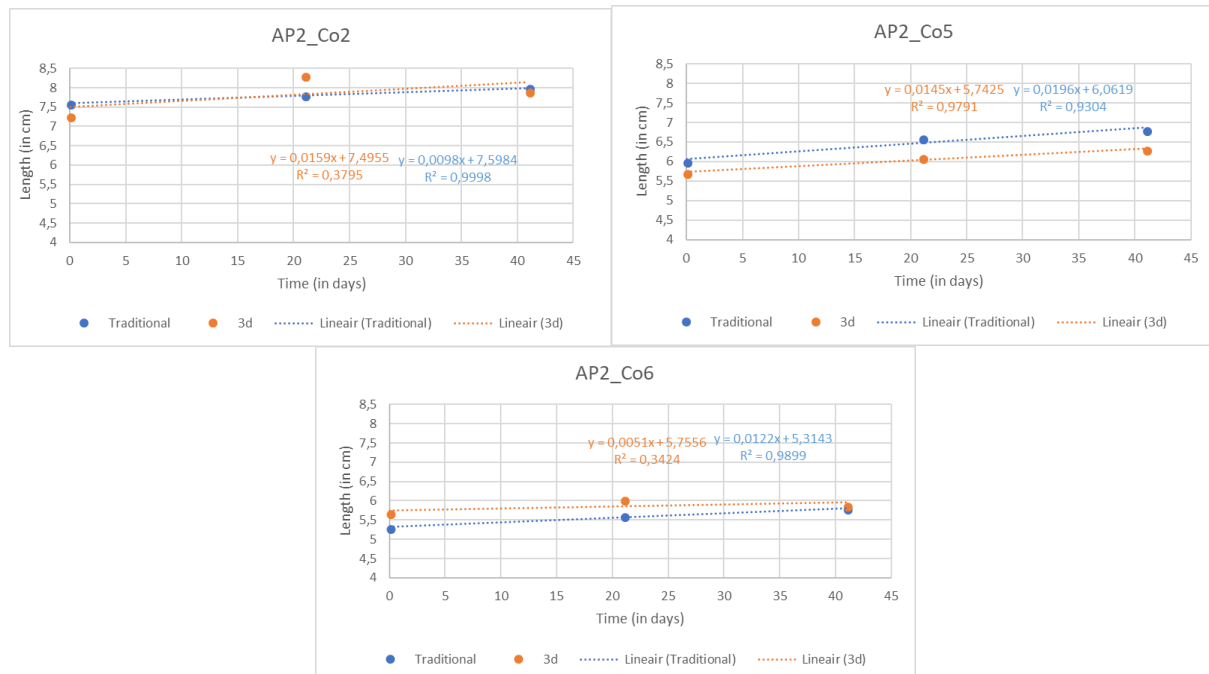


Figure 4.1-4.3: The growth of the corals from genotype AP2 in cm

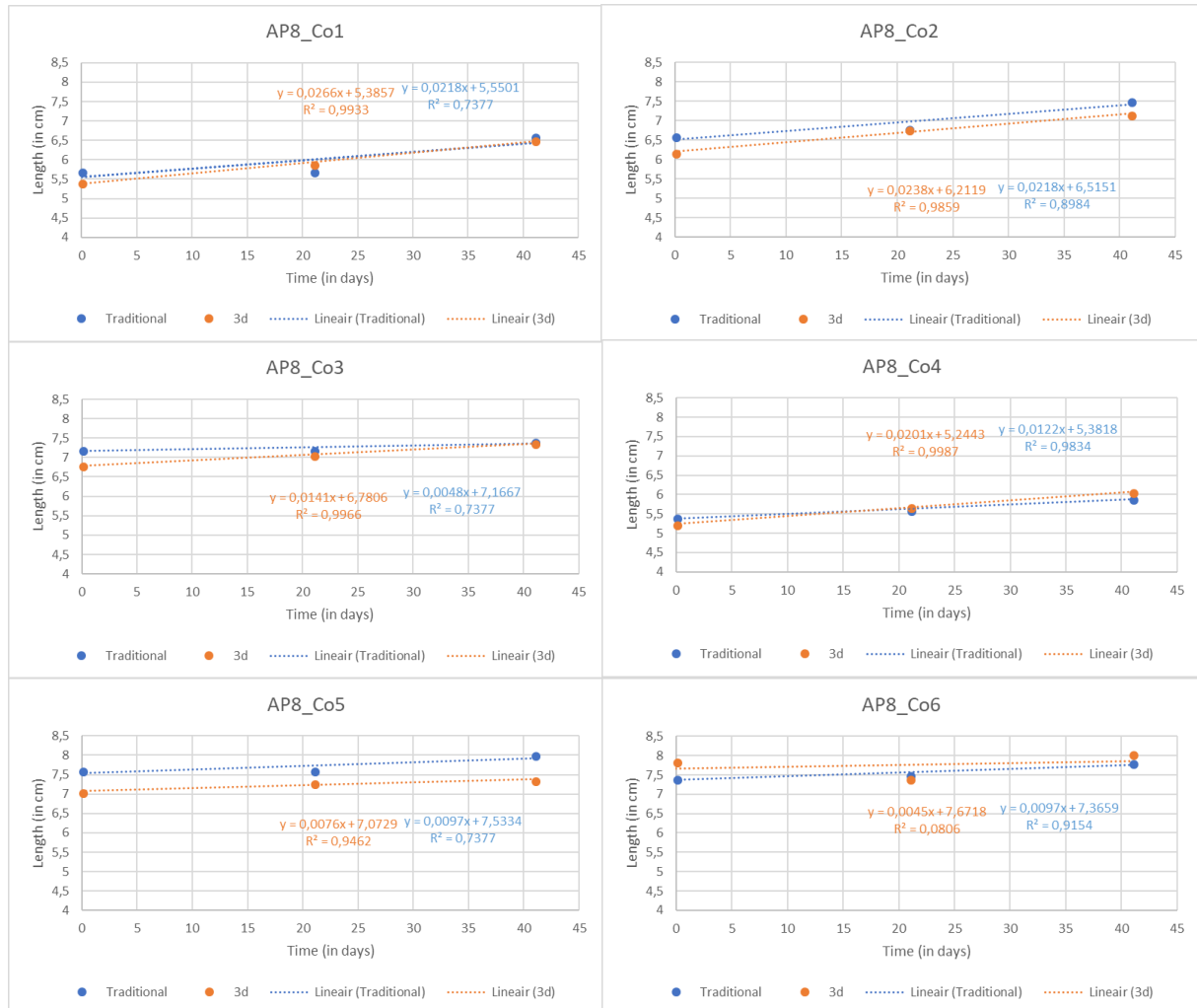


Figure 4.4-4.9: The growth of the corals from genotype AP8 in cm



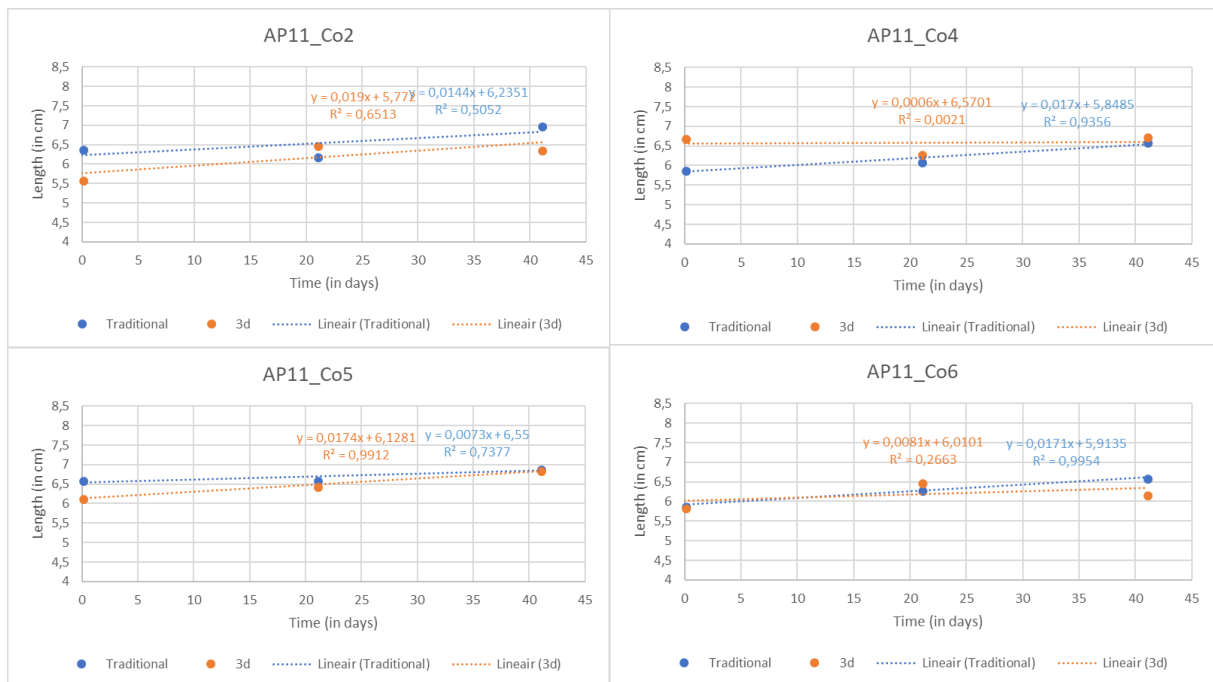


Figure 4.10-4.13: The growth of the corals from genotype AP11 in cm

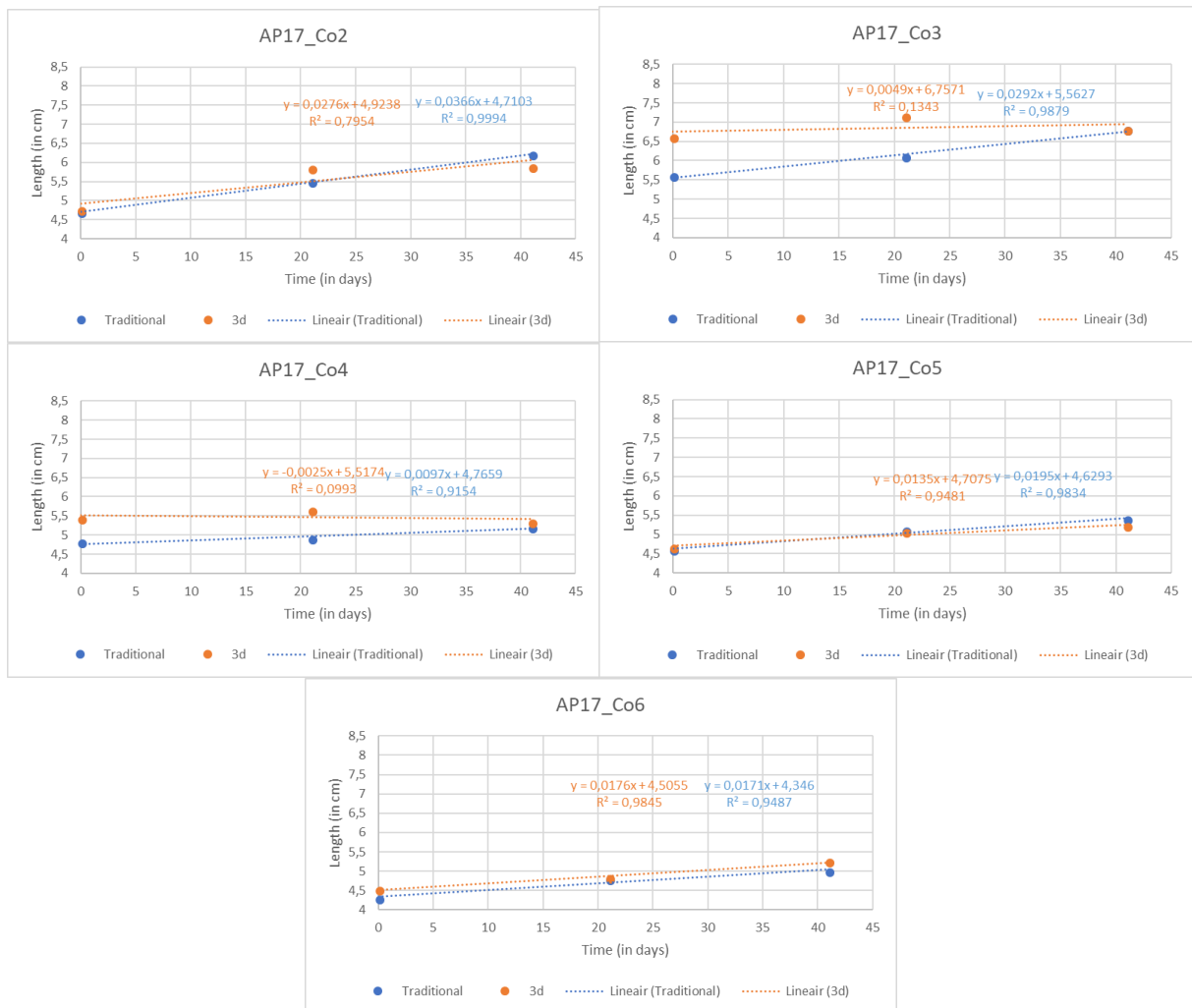


Figure 4.14-18: The growth of the corals from genotype AP17 in cm

## 4.2 MCA results

### 4.2.1 Time consumption

The time consumption for the Traditional method was on average 4 hours per batch of 24 corals. This translates to 0,167 hours/coral. For the 3d-reconstruction method, the average time was around 1 week, which this means 40 hours. This translates to 1,667 hours/coral.

For the MCA the score for the traditional method for time consumption was  $0,95 \cdot 0,5 = 0,48$ . The score for the 3d-reconstruction method was  $0,5 \cdot 0,5 = 0,25$ .

### 4.2.2 Reliability

Table 4.1 is the reliability of the measurements taken with the 3d-reconstruction method. If the measurement is 'ok' in both the Agisoft and Rhino column, this is a successful measurement. In the first batch a lot of measurements failed due to inexperience with the camera and the coral not being in the movie at all times. This is not a problem caused by the method itself and therefore this measurement will not be included for the reliability. From this table a reliability of 97,9 percent for batch 2 and 3 can be deducted.

	1st Batch Agisoft	1st Batch Rhino	2nd Batch Agisoft	2nd Batch Rhino	3rd Batch Agisoft	3rd Batch Rhino
AP2_Co1	ok	ok	ok	ok	ok	ok
AP2_Co2	ok	-	ok	ok	ok	ok
AP2_Co3	-	-	ok	ok	ok	ok
AP2_Co4	-	-	ok	ok	ok	ok
AP2_Co5	ok	ok	ok	ok	ok	ok
AP2_Co6	ok	ok	ok	ok	ok	ok
AP8_Co1	ok	ok	ok	ok	ok	ok
AP8_Co2	ok	ok	ok	ok	ok	ok
AP8_Co3	ok	ok	ok	ok	ok	ok
AP8_Co4	ok	ok	ok	ok	ok	ok
AP8_Co5	ok	ok	ok	ok	ok	ok
AP8_Co6	ok	ok	ok	ok	ok	ok
AP11_Co1	-	-	ok	ok	ok	ok
AP11_Co2	ok	ok	ok	ok	ok	ok
AP11_Co3	-	-	ok	ok	ok	ok
AP11_Co4	ok	ok	ok	ok	ok	ok
AP11_Co5	ok	ok	ok	ok	ok	ok
AP11_Co6	ok	ok	ok	ok	ok	ok
AP17_Co1	-	-	ok	ok	ok	ok
AP17_Co2	ok	ok	ok	ok	ok	ok
AP17_Co3	ok	ok	ok	ok	ok	ok
AP17_Co4	ok	ok	ok	ok	ok	ok
AP17_Co5	ok	ok	ok	ok	ok	ok
AP17_Co6	ok	ok	ok	-	ok	ok

Table 4.1: Reliability of the measurements with 3d-reconstruction

LENGTH	1ST BATCH	2ND BATCH	3RD BATCH
AP2_CO1	ok	ok	-
AP2_CO2	ok	ok	ok
AP2_CO3	ok	ok	ok
AP2_CO4	ok	ok	ok
AP2_CO5	ok	ok	ok
AP2_CO6	ok	ok	ok
AP8_CO1	ok	ok	ok
AP8_CO2	ok	ok	ok
AP8_CO3	ok	ok	ok
AP8_CO4	ok	ok	ok
AP8_CO5	ok	ok	ok
AP8_CO6	ok	ok	ok
AP11_CO1	ok	ok	ok
AP11_CO2	ok	ok	ok
AP11_CO3	ok	ok	ok
AP11_CO4	ok	ok	ok
AP11_CO5	ok	ok	ok
AP11_CO6	ok	ok	ok
AP17_CO1	ok	ok	ok
AP17_CO2	ok	ok	ok
AP17_CO3	ok	ok	ok
AP17_CO4	ok	ok	ok
AP17_CO5	ok	ok	ok
AP17_CO6	ok	ok	ok

Table 4.2: Reliability of the measurements with linear extension

Table 4.2 shows the reliability of the linear extension method. This table didn't incorporate the fact that there were 2 times where the photo of the coral was redone the day after, because the quality of the photos was too bad to read the results. Incorporating this with the table in which only 1 measurement failed, the reliability was 97,9 percent for all 3 batches.

The score for the MCA for the reliability was for both  $0,979 \cdot 1 = 0,98$

#### 4.2.3 Precision

For the precision the first step was to compare the slope of the regression shown in 4.1 general results. This can be seen in table 4.3

SLOPE	TRADITIONAL	3D-RECONSTRUCTION
AP2_CO2	0,0098	0,0159
AP2_CO5	0,0196	0,0145
AP2_CO6	0,0122	0,0051
AP8_CO1	0,0218	0,0266
AP8_CO2	0,0218	0,0238
AP8_CO3	0,0048	0,0141
AP8_CO4	0,0122	0,0201
AP8_CO5	0,0097	0,0076
AP8_CO6	0,0097	0,0045

AP11_CO2	0,0144	0,019
AP11_CO4	0,017	0,0006
AP11_CO5	0,0073	0,0174
AP11_CO6	0,0171	0,0081
AP17_CO2	0,0366	0,0276
AP17_CO3	0,0292	0,0049
AP17_CO5	0,0195	0,0135
AP17_CO6	0,0171	0,0176

Table 4.3: Slope of regression line

From this table a two-tailed paired t-test was done. The result from this t-test was  $p = 0,330323$ . This meant that the results were not very likely caused by chance and that the  $R^2$  could be used as a viable way of comparing precision between these 2 methods.

Table 4.4 shows the  $R^2$  of all the different measurements.

$R^2$	TRADITIONAL	3D-RECONSTRUCTION
AP2_CO2	0,9998	0,3795
AP2_CO5	0,9304	0,9791
AP2_CO6	0,9899	0,3424
AP8_CO1	0,7377	0,9933
AP8_CO2	0,8984	0,9859
AP8_CO3	0,7377	0,9966
AP8_CO4	0,9834	0,9987
AP8_CO5	0,9462	0,7377
AP8_CO6	0,9154	0,0806
AP11_CO2	0,5052	0,6513
AP11_CO4	0,9356	0,0021
AP11_CO5	0,7377	0,9912
AP11_CO6	0,9954	0,2663
AP17_CO2	0,9994	0,7954
AP17_CO3	0,9879	0,1343
AP17_CO4	0,9154	0,0993
AP17_CO5	0,9834	0,9481
AP17_CO6	0,9487	0,9845

Table 4.4:  $R^2$  of the regression lines

From this table the average  $R^2$  per method was calculated as shown in table 4.5

$R^2$	TRADITIONAL	3D-RECONSTRUCTION
AVERAGE	0,897089	0,631461

Table 4.5: Average  $R^2$  of the regression lines

This directly translated to the score for the MCA as the score was equal to the  $R^2$  and the weight for this criterium was 1. This meant that the score for the traditional method on the precision was 0,90 and for the 3d-reconstruction was 0,63.

#### 4.2.4 Type of measurement

The traditional method is able to measure the length and the width, but not able to measure the area and the volume. For the ability to measure length and width, this method received 0,25 points.

The 3d-reconstruction is able to measure the length, the width, the area and the volume of the coral. For the ability to measure all different types of measurements, this method received 1 point.

The score for the MCA on the type of measurements for the traditional method was  $0,25 \cdot 1 = 0,25$ . The score on the type of measurements for the 3d-reconstruction method was  $1 \cdot 1 = 1$ .

#### 4.2.5 Result MCA

The final result of the Multi Criteria Analysis can be seen in table 4.6. The 3d-reconstruction gets the highest score

CRITERIA	3D-RECONSTRUCTION	LINEAR EXTENSION
TIME CONSUMPTION	0,25	0,48
RELIABILITY	0,98	0,98
PRECISION	0,63	0,90
TYPE OF MEASUREMENT	1	0,25
TOTAL	2,86	2,61

Table 4.6: Final result of the MCA

## 5. Conclusion and discussion

### 5.1 Conclusion

According to the MCA, the best method for measuring the growth of *Acropora palmata* in a nursery setup, when comparing 3d-reconstruction with linear extension is 3d-reconstruction. The reason this is the best, is based on the 4 criteria that were assessed in the multi criteria analysis. These were the time consumption, the reliability, the precision and the type of results. The time consumption was the least important criterium.

This doesn't mean that the 3d-reconstruction is the best method for measuring growth of corals, as for this research only 2 methods were compared and this was only based on use in a nursery setup. When using these methods on corals that are attached to a substrate a lot of difficulties for both methods will disappear and this might give very different results.

### 5.2 Acceptation or rejection of hypothesis

The hypothesis was rejected, because even though the 3d-reconstruction method was proven to be the more practical and reliable method. This was not by a big margin and there is a lot of possible speculation that could easily affect the score of the MCA and favor the linear extension method. The hypothesis was right about the fact that the usefulness of the 3d-reconstruction would be higher. But it failed to predict that the precision of the linear extension would be higher as well as the two methods being equal on the reliability.

### 5.3 Possible shortcomings

The main shortcoming of this research can be seen as the MCA itself, as this is not a completely objective way of valuing the methods. In this research the 3d-reconstruction method was according to the criteria set with this particular scoring and weighting the best method. However, not for everyone interested in this research, the same score would apply. Some researchers value time consumption more over the type of results or are more interested in what a method would cost. For these researchers, the linear extension might be more appealing. This research however does show in what criteria either of these methods excel. The scoring and weighting were optimized for the goals and research question that was used for this research. Therefore, for this research, the 3d-reconstruction method is clearly the best.

There are a few points where this research might not have been optimal. First of all, the time period of this research was relatively short. Coral grows very slowly and to clearly show growth over time for different corals, a longer time period is necessary. The growth measured in this research is too close to the possible measuring error that might occur. If the same research is done over a larger time period, the results are more reliable.

The 3d-reconstruction method requires a very powerful computer. The computer used during this research was relatively powerful, but still took a very long time to process the models at high quality. This meant that in order to create the models in time, the accuracy settings were lower than optimal. This should have only had a minor impact on the measurements of the models.

There is a bug in Rhino, the software that was used for measuring the dimensions of the corals in the 3d-reconstruction method. This bug occurred when the mesh had too many faces, this practically means the quality of the model is too high. For unknown reasons, Rhino was not able to split the coral from the rest of the mesh in these high-quality models. Therefore, the quality of the mesh had to be reduced from 3.000.000 faces to just 180.000. This was still more than enough to create a reliable model and research has shown that decreasing this mesh size will not influence the area of

the coral by more than a few percent (Huisman, 2017). Still this might have influenced the results a little bit.

The experiment was conducted on the boat that was used for transport to the nursery location. This means that the corals had to be taken out of the water for a short period of time. The corals came on board by genotype, this meant 6 at a time and they were kept in a bucket with seawater, the corals were on board for around 30 minutes. The individual corals were during measurement out of the water for no longer than 5,5 minutes. The corals did not show any severe stress in the form of bleaching during or shortly after the research.

The reason that the decision was made to conduct the experiment out of the water, was because the surge was too big. This meant that the water, and with it the coral, was moving too much for the software to create an accurate model. If this had not been the case, the experiment would have been carried out under water.

During this research the only camera that could be used was a GoPro Hero 4. This is a relatively cheap underwater camera, which creates nice recreational videos. However, for this research, the quality of the models would probably have been better, if a better camera was used.

The corals were secured to the line with a crimp that was tightly secured. The corals would eventually grow around the crimp. For this reason and because the crimp was exactly the same volume for every coral, this was not cut from the model. This has not had an impact on the growth in volume of the corals.

The models had to be scaled in the program Rhino by hand. This means that 2 points on the marker had to be selected with a known distance. This distance was 4,6 centimeters. If however, the person scaling the model put the point a millimeter to the side in the program, due to imperfections in the model or just missing the right location, the scaling of the model would be imperfect. Having this imperfection in the scaling, all the measurements taken from this model would be off by a certain margin. This might have had a slight influence on the results of this research.

After the scaling, the next step was to cut the coral loose from the rest of the mesh. This was also done by hand. Looking at the model where the edge of the coral was, a curve was drawn to cut the coral loose. If however, due to either imperfections in the model or missing the right location, the curve was not in the right place, the model would be imperfect. This has had an influence on the results of this research.

The coral was laying on a wooden block during the process of filming. The reason for this was to make sure it did not move during the process of filming. This meant that in the model, the bottom of the coral was attached to the wooden block. The surface that was cut loose, was flattened by the program. This means that any complex structures beneath the coral would be lost in the model. For this reason, the area, although still calculated, was not taken into account for the comparison in methods. This has also had an influence on the volumetric measurements of the corals, but because the corals were every time positioned in the same way, this should not have had a big impact on the difference in measurements per coral.

Because the corals used for this research were growing in the ocean, there was a possibility for predators and diseases to harm the coral. This would have been indicated by white spots on the coral. In the nursery around the corals used for the research, there were a few cases of corals dying to predation or diseases, however none of the corals used for the research were visibly affected.



When handling the corals, there was a possibility that one of them could break. This would explain a decrease in length and/or volume. This would have left the coral with a scar that would be visible for at least 3 weeks. This is the same period that it took the initial scars from the cutting to heal. No scars other than the ones from the initial cut have been observed. This means that none of the corals broke.

The biggest shortcoming of the traditional method was that the coral grows in all different directions in different speeds. This means that during one measurement, the longest length might have been in one direction and during the next measurement, the longest length was in a different direction. This together with the fact that it was sometimes hard to read the exact measurements, makes this a relatively unreliable method.

The other shortcoming in the traditional method was that the angle at which the photo was taken could influence the measurement in the photo. This was because the coral was not always completely flat on the surface at which the measuring tape was attached. This meant that the camera should always be exactly above the coral at a 90-degree angle to get a reliable measurement and that was hard to do on a moving boat.

## 5.4 Recommendations for future research

### 5.4.1 improvement of the method

The first recommendation for further research on this topic is to repeat this experiment with an improved method. This will ensure that the results from this research are correct, as there were a lot of possible shortcomings in the process of this research. This new method should be optimized to deal with all the shortcomings mentioned in the chapter 5.3.

### 5.4.2 optimization of the Agisoft/Rhino settings

One possibility for further research is to optimize the process in Agisoft and Rhino for the 3d-reconstruction. This would be very useful information for people working with these 2 programs on a daily basis. A possible set up for this experiment would be very similar to this experiment, but instead of taking measurements on a lot of different corals, this should be done on the same coral. This would mean that this coral is worked with for a longer period of time and therefore this would be optimal to do under water.

### 5.4.3 3d-reconstruction

Research has already shown that this method is very useful for measuring growth of transplanted corals (Huisman, 2017). For these corals a lot of the possible shortcomings discussed in chapter 5.3 do not apply, because they are attached to a surface. For these transplanted corals a comparison could also be made between the traditional method and the 3d-reconstruction. For this scenario the 3d-reconstruction should be a much better option.

## 5.5 Overview

The corals all over the world are under massive threat of various causes, ranging from natural disaster to predation and sickness. All together this has led to an enormous decrease in coral

coverage in many places on earth. This is especially the case in the Caribbean. For this reason, it is very important to invest in new technologies and methods for monitoring and sustaining the reefs around the world. In order to successfully monitor these reefs and sustain them and where necessary intervene, a good method for measuring growth is vital. Hopefully this research will assist in creating/optimizing a method for measuring the growth of these corals in order to preserve the reefs all around the world.

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## Appendix 1: list of materials

- Diving buddy pair with a lot of experience (50+ dives)
- Diving gear
- GoPro Hero 4
- Wooden block
- Markers
- Wooden plate to block influence of sun and wind
- Box to transfer corals from seafloor to surface
- Box to keep the corals submerged when on the boat
- Diving computer to keep track of time
- Coral tags
- Crimp sleeves
- Monofilament line
- *Acorpora palmata* (Elkhorn coral)
- Coral nursery setup
- Boat
- Measuring tape
- Laptop
- Rhinoceros 3d software
- Agisoft scan software

## Appendix 2: table of coral growth

LENGTH	1ST BATCH TRADITIONAL	2ND BATCH TRADITIONAL	3RD BATCH TRADITIONAL	1ST BATCH 3D- RECONSTRUCTION	2ND BATCH 3D- RECONSTRUCTION	3RD BATCH 3D- RECONSTRUCTION
AP2_CO1	5,4	6,4		6,405	6,905	6,985
AP2_CO2	7,6	7,8	8	7,26	8,313	7,902
AP2_CO3	9,8	10	10,7		9,421	9,81
AP2_CO4	5,2	5,3	5,6		4,98	5,226
AP2_CO5	6	6,6	6,8	5,718	6,097	6,311
AP2_CO6	5,3	5,6	5,8	5,674	6,03	5,879
AP8_CO1	5,7	5,7	6,6	5,411	5,893	6,504
AP8_CO2	6,6	6,8	7,5	6,179	6,78	7,155
AP8_CO3	7,2	7,2	7,4	6,79	7,057	7,368
AP8_CO4	5,4	5,6	5,9	5,236	5,684	6,061
AP8_CO5	7,6	7,6	8	7,052	7,275	7,362
AP8_CO6	7,4	7,5	7,8	7,847	7,407	8,04
AP11_CO1	6,2	6,8	7,4	6,554	6,903	
AP11_CO2	6,4	6,2	7	5,611	6,502	6,384
AP11_CO3	5,6	5,9	6,1	5,701	6,01	
AP11_CO4	5,9	6,1	6,6	6,711	6,293	6,741
AP11_CO5	6,6	6,6	6,9	6,147	6,454	6,86
AP11_CO6	5,9	6,3	6,6	5,855	6,498	6,179
AP17_CO1	4,2	4,9	5,4	5,071	5,332	
AP17_CO2	4,7	5,5	6,2	4,762	5,836	5,887
AP17_CO3	5,6	6,1	6,8	6,614	7,153	6,807
AP17_CO4	4,8	4,9	5,2	5,432	5,641	5,327
AP17_CO5	4,6	5,1	5,4	4,671	5,066	5,223
AP1_CO6	4,3	4,8	5	4,531	4,823	5,254

Table 8.1: growth of corals measured with traditional and 3d-reconstruction method in cm